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TECHNICAL NOTE

A rapid renal clearance methodology for dextran

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Dextrans are useful probes of glomerular function. As dextrans are thought to be neither secreted nor reabsorbed by the renal tubule [1, 2], their plasma and urine concentrations directly reflect glomerular filtration. Indeed, renal clearance studies using neutral dextran with different molecular weights but uniform chemical composition allow the size selective transport properties of the glomerulus to be directly assessed [2–4]. Other neutral polymers such as polyvinylpyrrolidone [5–7] and polyethylene glycol [8] have also been used.

Studies of glomerular transport using dextrans were first attempted using fractions of limited polydispersity, treated as single solutes [9, 10]. Difficulties were encountered, however, since the residual polydispersity of the dextran fractions resulted in a time dependence of the measured clearance as the average molecular weight of the remaining dextran in plasma increased [1, 11, 12]. Wallenius [1] described an alternative approach by injecting polydisperse dextran intravenously, followed by a molecular weight characterization of dextran in the plasma and urine samples. This approach yielded more consistent results and was especially advantageous since the entire molecular weight range of interest could be studied in a single experiment. The molecular weight characterization technique of turbidimetric titration described by Wallenius [1] was of limited resolution and proved impractical. Others subsequently developed chromatographic techniques such as gel filtration or gel permeation chromatography for this purpose [13–16]. In spite of these developments, renal clearance studies using polydisperse dextran have remained tedious to perform. A major limitation has been the time required for characterizing the molecular weight distribution of dextran on conventional gel permeation chromatographic systems. Moreover, maintenance of a constant plasma concentration of polydisperse dextran at each molecular weight, a requirement for precise renal clearance determinations [17, 18], has not been technically possible as the glomerulus ultrafilters a disproportionate fraction of the lower molecular weight solutes in a polydisperse dextran sample.

We have described methods using high performance gel permeation chromatography for characterizing the molecular weight distribution of neutral dextran that can be performed rapidly [19]. We describe below the application of this methodology to renal clearance experiments in unanesthetized, conscious dogs and investigate the effect of changing plasma dextran concentrations on the accuracy of dextran fractional clearance determinations.

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Methods

Seven lab mix mongrel dogs (5 female, 2 male) weighing 20 to 35 kg were each studied at least twice (usually three times) by three different experimental protocols. Prior to each experiment they were fasted overnight and allowed free access to water. The animals were studied unanesthetized under minimum restraint.

Twenty ml/kg of 5% dextrose in water was administered over a 20 minute period at the start of a clearance experiment to promote diuresis. A catheter was passed into the bladder, and plasma samples were taken for blank assays. A priming dose of creatinine (90 mg/kg, Sigma Chemical Co., St. Louis, Missouri, USA), sodium p-aminohippurate or PAH (8 mg/kg, Merck Sharp & Dohme, West Point, Pennsylvania, USA), dextran T10 (390 mg/kg, Pharmacia Fine Chemicals, Piscataway, New Jersey, USA) and dextran T40 (130 mg/kg, Pharmacia) was prepared in a 0.9% NaCl solution and administered as a bolus injection. Sustaining 0.9% NaCl solutions, containing creatinine and PAH, followed the bolus injection to replace urinary losses of these solutes. Twenty to thirty minutes were allowed for the equilibration of these solutions. Urine collected during this time was discarded, and all urinary fluid loss was returned intravenously as a 0.45% NaCl solution. A 20 to 30 minute clearance interval was utilized with catheter drainage of the bladder and a terminal air washout. Plasma samples were taken just prior to the start and end of each of three urine collection periods.

Three different experimental protocols were performed concerning the plasma concentrations of dextran. In the first case, no additional dextran solutions were administered and the plasma dextran concentration was allowed to fall during the experiment. This is referred to as the bolus only protocol (B). During the second protocol (S), dextran T10 was added to the creatinine and PAH sustaining solutions with the amount added approximating urinary loses of total dextran. Urinary reinfusion (R) was performed as the third experimental protocol. Urine was continuously collected in a small reservoir, and a pump was used to reinfuse urine into a forelimb vein. Urine samples were taken from the reservoir. Before reinfusion, urine was passed through a 0.2 μ filter (Fischer Scientific Co., Tustin, California, USA) to remove any bacteria that may have contaminated the reservoir. Maintenance of a constant volume in the reservoir

was performed by matching the flow rate of the pump to the urine flow rate. No sustaining solution of creatinine and PAH was used during urinary reinfusion. During this protocol, the urinary loss of dextran is exactly balanced by reinfusion into the blood stream making the plasma concentration at each molecular weight relatively constant.

The three protocols for the administration of dextran were selected for the following reasons. The B protocol represents the simplest experimental strategy and has been widely used by previous investigators. During this protocol plasma dextran concentrations decrease rapidly during the experiment, especially those at low molecular weight that traverse the glomerulus unimpeded. The low and falling plasma dextran concentrations may invalidate the simple calculation of renal clearance since this calculation dose not account for the delay time between blood sampling and solute appearance in the urine nor the difference between venous and arterial concentrations [17, 18]. The S protocol seeks to correct for the rapid loss of low molecular weight dextran by continuous replenishment of dextran T10. This replacement is, however, only an approximation of urinary losses. The R protocol, while technically difficult and clearly not applicable for human experimentation, provides the best stability of all dextran plasma concentrations, as the dextran lost in the urine is returned to the vascular space. Artifacts of clearance that result from fluctuating plasma levels should be minimal from experiments conducted with the R protocol but maximum with the B protocol.

Creatinine concentrations in urine and plasma were determined using a Beckman-2 Creatinine Analyzer (Fullerton, California, USA). Concentrations of PAH were determined by the method described by Waugh and Beall [20].

Chromatography

Chromatography was performed by using a Waters (Model 6000A) solvent delivery system with a Waters (Model U6K) sample injector. Column effluents were monitored by using a differential refractive index detector (Waters Model R401). Voltage output from the detector was simultaneously monitored by a chart recorder and an Apple II+ microcomputer as described previously [19]. The column buffer was 0.01 M phosphate, pH 6.5, containing 0.15 M ammonium acetate, and all chromatographic separations were performed at ambient temperature. A TSK-G3000SW column (60 cm × 0.75 cm, Cole Scientific, Calabasas, California) was used and calibrated with dextran standards of very low polydispersity [19]. The column flow rate was set at a nominal pump setting of 1 ml/min. Sample volumes ranged from 100 to 200 μl for plasma and 20 to 50 μl for urine. With this system a molecular weight characterization of dextran can be performed in less than 45 minutes. More details of this chromatographic system have been previously described [19].

Sample preparation

Samples of urine and plasma were deproteinized by adding four volumes of a saturated picric acid solution followed by centrifugation for 15 minutes. Dextran was then recovered from these solutions by precipitating with nine volumes of 100% cold ethanol, lyophilizing, and reconstituting in column buffer. Independent recovery experiments from plasma and urine showed a small but significant fractionation of dextran following treatment by picric acid. Recovery of dextran varied from approximately 90% at low molecular weight to 100% at high molecular weight. The recovery from plasma and urine was quantitatively identical.

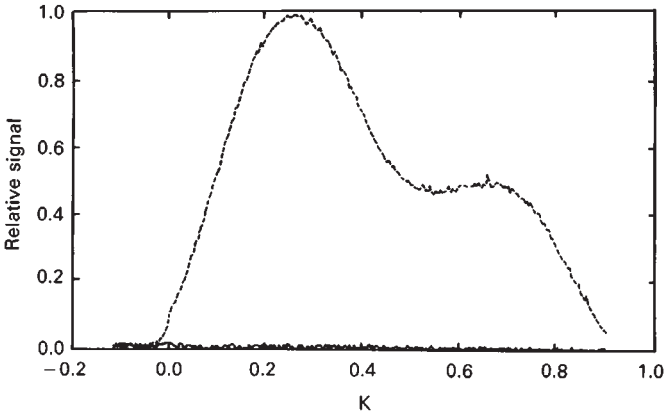

Fig. 1. *Relative signal from the chromatographic system as a function of the column retention volume K for a blank (solid line) and experimental (dashed line) sample from plasma.* The value of K = 0.8 corresponds to a 3000 dalton dextran, K = 0.6 to a 12,000 dalton dextran, K = 0.4 to a 29,000 dalton dextran, and K = 0.2 to a 47,000 dalton dextran [19].

As differential refractometry is not a selective detection system, it was important to demonstrate that the above procedures resulted in signals that reflect only dextran concentration. Figure 1 shows an example of the relative signal for blank (solid line) and experimental (dashed line) plasma samples as a function of the column retention volume K. The signal obtained from the blank sample was essentially zero for retention volumes less than 0.9 (dextran molecular weights greater than 1000 [19]) demonstrating that the signal is a direct measure of dextran concentration.

Data handling and statistics

The clearance for each solute of interest (C_i) was calculated by the following equation

$$C_i = U_i V / P_i \quad (1)$$

where U_i and V are the solute concentration in urine and the volume flow rate of urine, respectively. The value of P_i is the arithmetic mean of the plasma concentrations that bracket the urine collection period. Virtually identical results were obtained when the logarithmic mean plasma concentration was alternatively used. No correction was made for the delay time between blood sampling and the arrival of the solute in the bladder for any protocol. Since exogenous creatinine clearance has been previously shown to be a good measure of the glomerular filtration rate in dogs [18], dextran fractional clearance was calculated as the ratio of dextran to creatinine clearance. The dependence of dextran fractional clearance on molecular weight was interpolated at 150 different molecular weights to facilitate further calculations. The data are plotted in all figures by connecting the fractional clearance values at these interpolated dextran molecular weights with straight lines. The filtration fraction (FF) was estimated by dividing the creatinine clearance by the PAH clearance.

Table 1. Creatinine clearance (C_{Cr}), PAH clearance (C_{PAH}), filtration fraction (FF), and urine flow rates (V) for the experimental conditions of bolus only (B), bolus and sustain (S), and urinary reinfusion (R).

Conditions	C_{Cr} *ml/min*[a]	C_{PAH} *ml/min*[b]	FF	V *ml/min*
B	74.6 (15.1)[c]	252 (36)	0.295 (0.035)	3.88 (0.91)
S	83.1 (15.5)	273 (41)	0.303 (0.027)	4.46 (0.68)
R	66.8 (13.1)[c]	232 (36)[c]	0.291 (0.053)	4.72 (1.38)

The standard deviation follows the mean value in parentheses.
[a] Values between B, S, and R are significantly different at the $P < 0.01$ level.
[b] Values between B, S, and R are significantly different at the $P < 0.05$ level.
[c] Significantly different from the S protocol at the $P < 0.05$ level.

Estimates of the components of variance within clearance periods of each experiment, within experiments on each dog, within dogs, and within treatment protocols using a nested analysis of variance [21] showed significant variance contributions at each lower level. A single mean clearance value for each dog was therefore used in an analysis of variance with repeated measures [22] to analyze the differences between experimental protocols. Simultaneous multiple comparisons were made by using a paired Student's *t*-test with modified Bonferroni confidence limits [22].

Results

Measured values of creatinine clearance, PAH clearance, FF, and urine flow rate are shown in Table 1. These values and their interanimal variability are similar to that reported by others for unanesthetized dogs [23]. Significant differences between the three experimental protocols were found for creatinine and PAH clearance, but no differences in FF or urine flow rates were observed. Creatinine clearance for the S protocol was significantly larger than for both the R and B protocols, and PAH clearance for the S protocol was larger than for the R protocol.

Examples of data illustrating changes in plasma dextran concentrations during the R and B experimental protocols are shown in Figures 2 and 3, respectively. In these figures, relative plasma dextran concentration is plotted as a function of the column retention volume K at various times following the initiation of the experiment. Relative plasma dextran concentrations at each molecular weight were maintained relatively constant during the R protocol but dropped substantially during the B protocol. Figure 3 demonstrates that the decrease in plasma dextran concentration depends on molecular weight, the fall being greatest for the smaller solutes (larger values of K). Plasma dextran concentration changes during the S protocol were intermediate between the R and B protocols.

Dextran fractional clearance as a function of dextran molecular weight and Stokes radius for all three experimental protocols is shown in Figure 4. The values of dextran Stokes radius R_s (in Å) were computed by the following equation [19, 24, 25]

$$R_s = 0.305\ M^{0.47} \quad (2)$$

where M is the molecular weight of dextran determined by column calibration. The results from each experimental protocol showed a dependence of dextran fractional clearance on molecular weight comparable to that reported by others [1, 2, 11]. As the molecular weight decreases, the fractional clearance increases until approximately 8000 daltons (R_s = 21 Å) upon which further decreases in molecular weight lead to a decrease in the fractional clearance. The dextran fractional clearance for the B protocol was significantly lower than for the R and S protocols at only scattered dextran molecular weights between 3000 and 5000 daltons when only *t*-tests were performed [26]. When the more powerful statistical test of analysis of variance was employed, however, significant differences in dextran fractional clearance were found between the experimental protocols from 3000 to 18,900 daltons. Subsequent *t*-tests with modified Bonferroni confidence limits failed to identify which individual protocols were different.

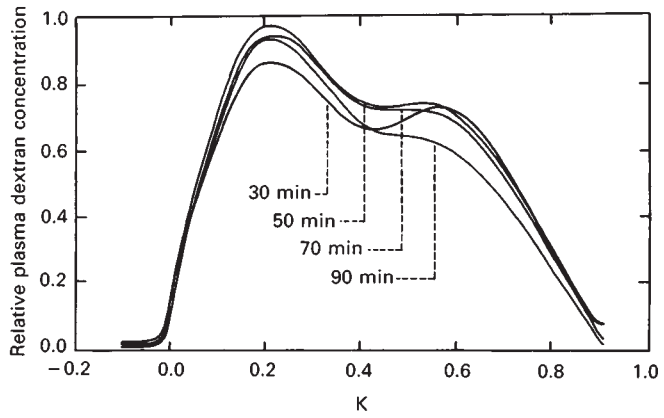

Fig. 2. *Relative plasma dextran concentration plotted as a function of the column retention volume K at various times for a typical urinary reinfusion (R) experiment.* The labels correspond to times after the initiation of the experiment. The curves have been smoothed by hand for clarity. The value of K = 0.8 corresponds to a 3000 dalton dextran, K = 0.6 to a 12,000 dalton dextran, K = 0.4 to a 29,000 dalton dextran, and K = 0.2 to a 47,000 dalton dextran [19].

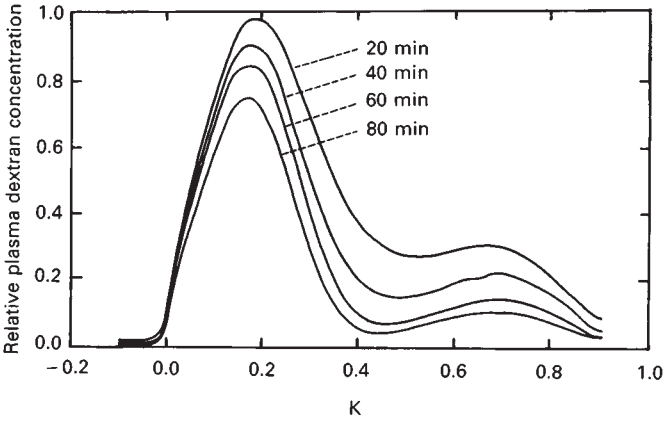

Fig. 3. *Relative plasma dextran concentration plotted as a function of the column retention volume K at various times for a typical bolus only (B) experiment.* The labels correspond to times after the initiation of the experiment. The curves have been smoothed by hand for clarity. The value of K = 0.8 corresponds to a 3000 dalton dextran, K = 0.6 to a 12,000 dalton dextran, K = 0.4 to a 29,000 dalton dextran, and K = 0.2 to a 47,000 dalton dextran [19].

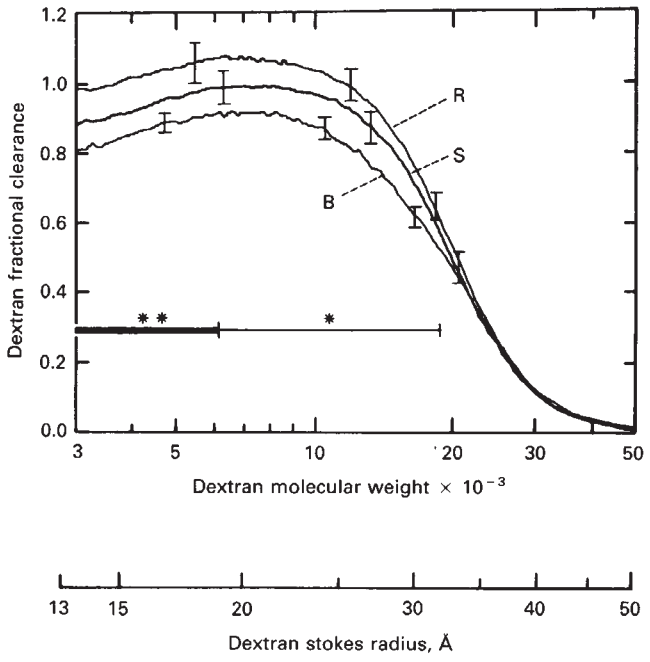

Fig. 4. *Dextran fractional clearance plotted as a function of dextran molecular weight and Stoke radius for the bolus only (B), bolus and sustain (S), and urinary reinfusion (R) experimental protocols.* The vertical bars shown at selected data points illustrate the standard error of the mean. The horizontal bars denote regions of significant difference between the three experimental protocols as determined by analysis of variance with repeated measures. A single asterisk denotes $P < 0.05$ and a double asterisk $P < 0.01$.

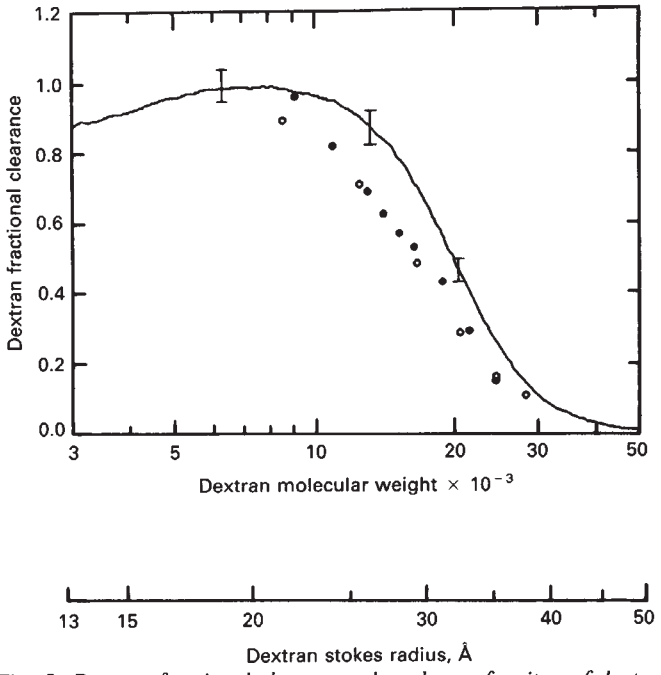

Fig. 5. *Dextran fractional clearance plotted as a funciton of dextran molecular weight and Stokes radius for the S protocol compared with previously published data.* Previous data is shown by either open [1] or closed [27] circles.

Discussion

The present study describes a new method for the molecular weight characterization of dextran for use in renal clearance experiments. The chromatographic equipment and columns were previously studied [19]. Since a nonspecific refractive index detector is used with the chromatographic system, the successful application of this approach in renal clearance studies requires that dextran be first isolated chemically from urine and plasma. With the technique described, dextran is almost completely recovered and the output signal from the chromatographic system is dependent only on dextran concentration in both the plasma and urine samples. In agreement with these observations, Wallenius [1] previously reported complete dextran recovery using similar chemical isolation techniques. Figure 5 compares dextran fractional clearance obtained by the S protocol with results from two previous studies using dextran in dogs [1, 27]. The present results are in reasonable agreement considering the differences in methodology used. The primary advantage of the present method is the speed of analysis with improved chromatographic resolution [28, 29].

The present study also examines the effect of changing plasma dextran concentration on its measured fractional clearance. For this purpose, it would be ideal if the different experimental protocols did not substantially affect glomerular function. Table 1 shows that differences in renal plasma flow rate and glomerular filtration rate occur during each experimental protocol and that some were statistically significant. As the present study was not designed to investigate these differences, we cannot provide a unique explanation for these results. We note only that during the R protocol, some hemolysis of red blood cells was observed that may have resulted in decreased creatinine and PAH clearances. The presence of free hemoglobin in plasma has been shown previously [30] to result in a simultaneous decrease in renal plasma flow rate and glomerular filtration rate similar to that described here. This effect of free hemoglobin may dominate the profound natriuresis that has been observed during urinary reinfusion in rats [31].

The differences in renal plasma flow rate and glomerular filtration rate between protocols somewhat complicate the interpretation of fractional clearance data since dextran fractional clearance has been shown previously to depend on glomerular hemodynamic conditions [2–4]. In the absence of changes in glomerular membrane properties, such as membrane area or permeability (that is, constant K_f), the fractional clearance of macromolecules varies inversely with SNGFR [4] or equivalently glomerular filtration rate. It is, however, important to note that large changes in hemodynamic parameters are necessary to alter dextran fractional clearance. For example, Chang and co-workers [2] determined a maximum decrease in dextran fractional clearance of 0.14 following a twofold increase in glomerular filtration rate and a threefold increase in renal plasma flow rate. The observed differences between protocols in renal plasma flow rate and glomerular filtration rate of 20 to 25% are, therefore, unlikely to have substantially affected dextran fractional clearances. While we cannot rule out the possibility that changes in glomerular hemodynamics altered

dextran fractional clearance, we note that these changes in hemodynamic conditions could only explain the differences between the R and S protocols.

The significant difference in dextran fractional clearance between the experimental protocols over the molecular weight range from 3000 to 18,900 is consistent with previous work on renal clearance methodologies [17, 18] and emphasizes the importance of maintaining a constant plasma concentration in studies of low molecular weight dextran. The errors incurred during the bolus only protocol may have resulted from either neglecting the delay time or sampling venous instead of arterial blood [32]. The latter phenomena results in errors that are largest for solutes that are rapidly cleared by the kidney and have large diffusional barriers to capillary–tissue transport. The magnitude of the difference in dextran fracional clearance between the S and B protocols for dextran with a Stokes radius of 15 Å is 8%. This value is in agreement with data reported for inulin by others (7%) [32]. These observations suggest that errors in dextran fractional clearance caused by rapidly changing plasma concentrations are small yet identifiable and that clearance studies using low molecular weight dextran should be performed with sustaining doses. It is important to note, however, that dextran fractional clearance is independent of changing plasma concentrations for dextran greater than 18,900 daltons, the molecular weight region of most interest in studies of glomerular barrier function.

Several previous studies [1, 2] have reported experimental data supporting the absence of significant secretion or reabsorption of dextran by the renal tubules. The present results, however, suggest that dextran of very low molecular weight (less than 5000 daltons) may be significantly reabsorbed. The smaller dextran fractional clearance observed for very low molecular weight dextran (Fig. 4) was independent of the experimental protocol employed and was present in every animal studied. It is noteworthy that all previous studies supporting the absence of tubular reabsorption or secretion of dextran were limited to solutes with Stokes radii greater than 18 Å [1, 2].

The decrease in dextran fractional clearance at very low molecular weight does not appear to result from the present methodology for three reasons. The recoveries of dextran from plasma and urine are quantitatively identical. The present results are in reasonable agreement with previous studies using dextran over the molecular weight range from 8000 to 50,000 daltons (18 to 50 Å) in dogs (Fig. 5) and other species [2, 11]. Moreover, we have shown previously [33] that this methodology yields results for in vitro experiments on hemofiltration membranes from human plasma solutions that are similar to those reported by others using different techniques.

In summary, we have described the application of a new method for characterizing the molecular weight distribution of dextran that permits more rapid processing of samples than conventional techniques. Using these methods, dextran fractional clearance for molecular weights between 8000 and 50,000 is similar to that reported previously. It is recommended that the determination of dextran fractional clearance at low molecular weight should be performed by using a sustaining dosage to prevent rapidly changing plasma dextran concentrations.

Acknowledgments

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References

1. Wallenius G: Renal clearances of dextran as a measure of glomerular permeability. *Acta Soc Med Upsalien* 4(Suppl):1–91, 1954
2. Chang RLS, Ueki IF, Troy JL, Deen WM, Robertson CR, Brenner BM: Permselectivity of the glomerular capillary wall to macromolecules. II. Experimental studies in the rat using neutral dextran. *Biophys J* 15:887–906, 1976
3. Chang RLS, Robertson CR, Deen WM, Brenner BM: Permselectivity of the glomerular capillary wall to macromolecules. I. Theoretical considerations. *Biophys J* 15:861–886, 1975
4. Deen WM, Bohrer MP, Brenner BM: Macromolecular transport across glomerular capillaries: Application of pore theory. *Kidney Int* 16:353–365, 1979
5. Hulme B, Hardwicke J: Human glomerular permeability to macromolecules in health and disease. *Clin Sci* 34:515–529, 1968
6. Lambert PP, Verniory A, Gassee JP, Ficheroulle P: Sieving equations and effective glomerular filtration pressure. *Kidney Int* 2:131–146, 1972
7. Robson AM, Giangiacomo J, Kienstra RA, Naqvi ST, Ingelfinger JR: Normal glomerular permeability and its modification by minimal change nephrotic syndrome. *J Clin Invest* 54:1190–1199, 1974
8. Jorgensen KE, Moller JV: Use of flexible polymers as probes of glomerular pore size. *Am J Physiol* 236:F103–F111, 1979
9. Brewer DB: Renal clearance of dextrans of varying molecular weight. *Proc Roy Soc Med* 44:561–563, 1951
10. Grotte G, Knutson RC, Bollman JL: The diffusion of dextrans of different molecular sizes to lymph and urine. *J Lab Clin Med* 38:577–582, 1951
11. Arturson G, Wallenius G: The renal clearance of dextran of different molecular sizes in normal humans. *Scand J Clin Lab Invest* 1:81–86, 1964
12. Raisz LG: Dextran and oxypolygelatin as plasma volume expanders: Renal excretion and effects on renal function. *J Lab Clin Med* 40:880–890, 1952
13. Hulme B, Hardwicke J: The measurement of renal permeability using labelled macromolecules. *Proc Roy Soc Med* 59:509–512, 1966
14. Hardwicke J, Hulme B, Jones JH, Ricketts CR: Measurement of glomerular permeability to polydisperse radioactively-labelled macromolecules in normal rabbits. *Clin Sci* 34:505–514, 1968
15. Mogensen CE: The glomerular permeability determined by dextran clearance using Sephadex gel filtration. *Scand J Clin Lab Invest* 21:77–82, 1968
16. Arturson G, Granath K: Dextrans as test molecules in studies of the functional ultrastructure of biological membranes. *Clin Chim Acta* 37:309–322, 1972
17. Smith HW: *The Kidney: Structure and Function in Health and Disease*. New York, Oxford University Press, 1951, pp. 39–62
18. Levinsky NG, Levy M: Clearance techniques, in *Handbook of Physiology, Section 8: Renal Physiology*, edited by Orloff J, Berliner RW. Washington, D.C., American Physiological Society, 1973, pp. 103–117
19. Frigon RP, Leypoldt JK, Uyeji S, Henderson LW: Disparity between Stokes radii of dextrans and proteins as determined by retention volume in gel permeation chromatography. *Anal Chem* 55:1349–1354, 1983
20. Waugh WH, Beall PT: Simplified measurement of p-aminohippu-

rate and other arylamines in plasma and urine. *Kidney Int* 5:429–436, 1974
21. SOKAL RR, ROHLF FJ: *Biometry*, (2nd ed). San Francisco, WH Freeman, 1981, pp. 271–320
22. GLANTZ SA: *Primer of Biostatistics* New York, McGraw-Hill, 1981, pp. 229–261
23. HOUCK CR: Statistical analysis of filtration rate and effective renal plasma flow related to weight and surface area in dogs. *Am J Physiol* 153:169–175, 1948
24. GRANATH KA: Solution properties of branched dextran. *J Colloid Sci* 13:308–328, 1951
25. GRANATH KA, KVIST BE: Molecular weight distribution analysis by gel chromatography on Sephadex. *J Chromatogr* 28:69–81, 1967
26. LEYPOLDT JK, FRIGON RP, DEVORE KW, HENDERSON LW: Renal clearance of dextran: A new, improved methodology. (abstract) *Kidney Int* 27:329, 1985
27. WHITESIDE C, SILVERMAN M: Determination of glomerular permselectivity to neutral dextrans in the dog. *Am J Physiol* 245: F485–F495, 1983
28. DUBIN PL: Aqueous exclusion chromatography. *Sep Purif Methods* 10:287–313, 1981
29. LEYPOLDT JK, FRIGON RP, HENDERSON LW: Chromatogram broadening of proteins and dextrans in size exclusion chromatography. *J Appl Polym Sci* 29:3533–3536, 1984
30. DEMARIA WJA, HARRIS JS: Effect of magnesium sulfate on the alterations in renal dynamics induced by intravenous hemoglobin. *Am J Physiol* 202:251–255, 1955
31. HARRIS RH, YARGER WE: Urine-reinfusion natriuresis: Evidence for potent natriuretic factors in rat urine. *Kidney Int* 11:93–105, 1977
32. BRUN C, HILDEN T, RAASCHOU F: The significance of the difference in systemic arterial and venous plasma concentrations in renal clearance methods. *J Clin Invest* 28:144–152, 1949
33. LEYPOLDT JK, FRIGON RP, HENDERSON LW: Dextran sieving coefficients of hemofiltration membranes. *Trans Am Soc Artif Intern Organs* 29:678–683, 1983